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Dynamic Behavior of Road High Cutting Rock Slope under the Influence of Blasting for Excavation

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Abstract

Based on the blasting vibration field test of a high cutting rock slope of Guanghe expressway in Guangdong province, numerical simulation is employed to estimate the dynamic behavior of the slope under blasting load. A simplified triangular blasting load is adopted to simulate the explosion. The velocity and displacement fields of the slope under blasting are analyzed and the result shows that the particle vibration velocity by the numerical simulation is basically consistent with that by field test. Elevation amplification effect exits in the process of attenuation of the particle peak velocity. The result also indicates that the particles on the surface of the slope have larger velocity and maximum displacement than the particles inside the slope, and the maximum displacement of particles does not have obvious rule to comply with.

Keywords: Road engineering; high slope; numerical simulation; dynamic behavior; blast loading

1. Introduction

The slope stability under influence of blasting for excavation has attracted more and more attentions. Excessive effect can induce slope collapse, slide or even worse debris flow which endangers public security. Consequently, it is necessary to investigate the dynamic behavior of slope under blasting. The present researches mainly focus on field tests and numerical simulations. Jin's work [1] concluded that steep terrain has significant influence on the dynamic behavior of slope under blasting. The relationship

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between slope type and slope effect value was investigated by Guo [2]. The single slope dynamic response was studied in [3]. The dynamic characteristics of jointed rock mass under blast loading were obtained by discrete element method [4-5]. FLAC-3D was employed to estimate the dynamic behavior of soil slope by Xia [6].

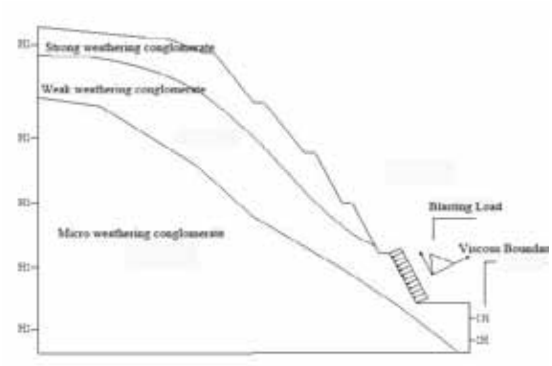
In this paper, the blasting excavation of a road high cutting rock slope is chosen to analysis the dynamic behavior of rock slope under blast loading. The procedures are simulated by FLAC-3D to obtain the velocity and displacement fields of the slope.

2. Numerical simulation

2.1. Geological conditions

The simulated high cutting rock slope is situated on the left side of Twenty-nine section K102+860~K103+030, with six steps and height of 58 meters. The slope mainly consists of three layers, strong, weak and micro weathering conglomerate, respectively. The strata occurrences do not vary differently, 39°∠57°, 47°∠62, 32°∠67°, 45°∠62°, respectively.

2.2. Definition of parameters



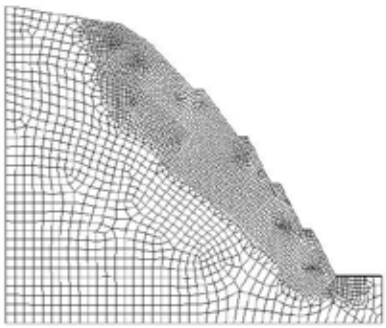


Fig. 1. Calculation diagram of slope model; Fig. 2. Mesh of slope model

Table1. Physics mechanical parameters of rock mass

Rock stratum	Strong	Weak	Micro
Density (kg/m3)	2100	2300	2350
Cohesion c (kPa)	35	60	70
Friction angle φ (°)	35	50	60
Poisson’s ratio μ	0.25	0.27	0.31
Young’s modulus E0 (GPa)	1.90	2.85	5.63
Bulk modulus K (GPa)	1.267	2.068	4.936
Shear modulus G (GPa)	0.760	1.124	2.148
Extension moludus (MPa)	0.51	0.77	0.91

This simulation aims at dynamic behavior of the slope under blasting in single hole. The simulated explosive charge is chosen as the actual charge, 24.6kg. Viscous boundary and Rayleigh damping are used to constraint the slope. On the trial-and-error basis, the minimum critical damping and center frequency are defined as 0.02 and 15 Hz, respectively.

The rock is described by the elastoplastic Mohr-Coulomb model. The calculation diagram and mesh of the slope are shown in Figure 1 and 2. Based on the field geological survey data and studies by Shen [7], the physics mechanical parameters of the rock mass are selected as in Table 1.

2.3. Definition of blast loading

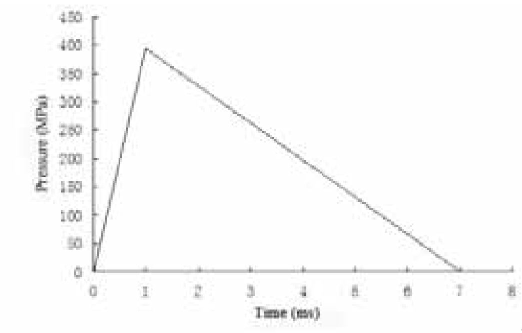
Explosion is a complex instantaneous process. It is difficult to accurately measure every detail of the explosion process at present. The widely applied approach is to predict the size of the explosion blast and attenuation by empirical formula or field particle vibration monitoring results. It is generally regarded the blasting load as a triangular pulse wave in numerical simulation. This simulation method requires the peak value and lasting time of the blasting load.

When the applied charge form is columnar uncouple charge, the peak value of the blasting load is defined by E.q (1)

$$P_0 = \frac{\rho_e D^2}{2(\gamma+1)} \left[\frac{d_c}{d_b} \right]^{2\gamma} \left(\frac{l_c}{l_b} \right)^{\gamma} n \qquad (1)$$

Where P_0 is the peak value of the blasting load; ρ_e corresponds to the density of the explosive. No.2 rock emulsified explosive is used in the field test, with the density of 1310 kg/m^3; D is the detonation velocity of the explosive, 4000 m/s herein. γ is the explosive isentropic exponent. The definition depends on the density of the charge. By Kahlemeyer [8], if ρ_e<1200 kg/m^3, γ=2.1; Otherwise, γ=3; d_c is the diameter of the charge, 50mm herein; d_b is the diameter of blast hole, 90mm herein; l_c, l_b are the length of charge and blast hole, respectively; n corresponds to increase multiples, n = 10 herein.

With respect to lasting time of the blasting, the value is assumed as 7 milliseconds by Chen and Henrych [9, 10]. Figure 3 shows the blasting load versus time curve. Blasting load (Mpa) is plotted along the vertical axis and time (ms) along the horizontal axis.



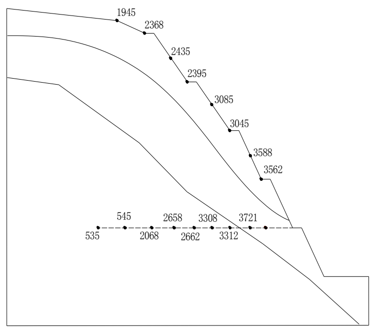


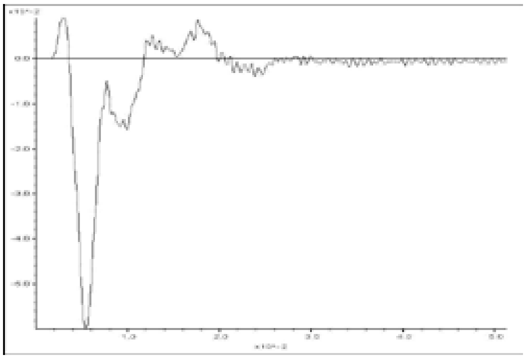
Fig. 3 Curve of blasting load versus time ; (left)
Fig. 4 Positions of the monitoring nodes (right)

2.4. Results analysis

The simulated blasting load is placed at hole which is located at the first step of the slope. To monitor the dynamic response of the blasting, a set of nodes are selected. The positions of the nodes are given in Fig 4.

2.4.1. Velocity

Fig 4 and 5 illustrate the numerical vibration velocity of the node 3588. The node is 17.5m far away from the start sites of the blasting. The maximum vertical (z direction) and horizontal (x direction) velocities by numerical computation are 6.00 cm/s and 5.46 cm/s, respectively, while the tested values are 4.84 cm/s and 4.64 cm/s.



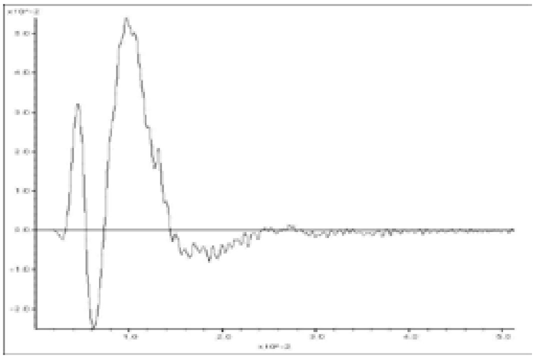
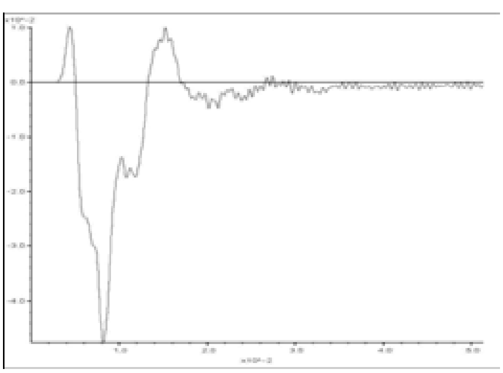


Fig. 5 Z-direction velocity time-history curve of node 3588; (left)
Fig. 6 X-direction velocity time-history curve of node 3588 (right)



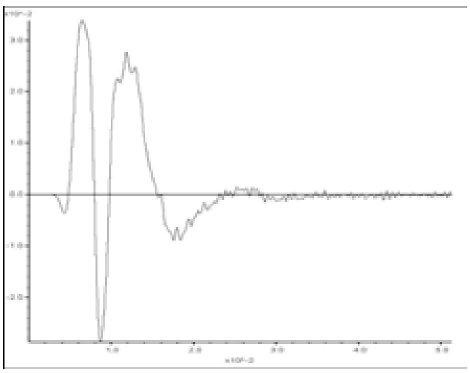
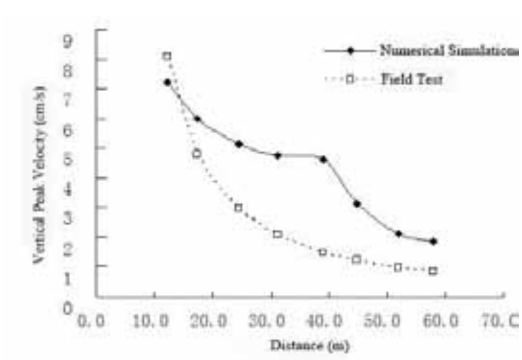


Fig. 7 Z-direction velocity time-history curve of node 3058; (left)
Fig. 8 X-direction velocity time-history curve of node 3058 (right)



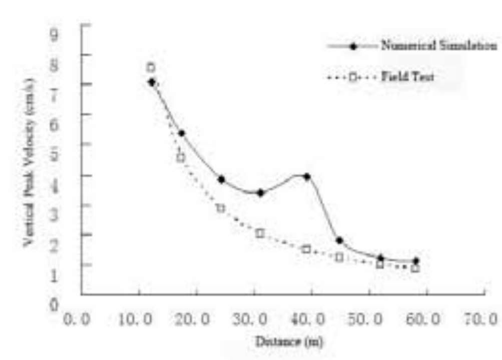
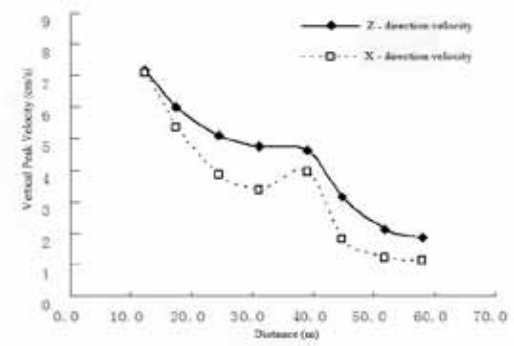


Fig. 9 Z-direction velocity attenuation curve of particle on the slope surface; (left)
Fig. 10 X-direction velocity attenuation curve of particle on the slope surface (right)



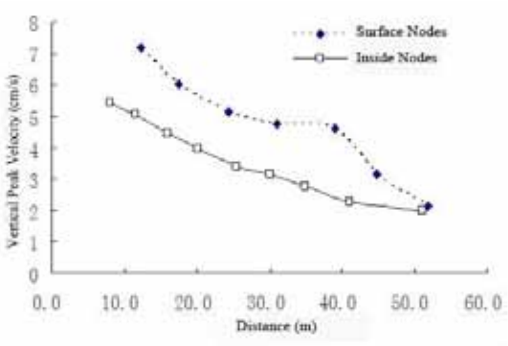


Fig. 11 Comparison between Z-direction velocity and X-direction velocity on the slope surface; (left)
Fig. 12 Z-direction velocity attenuation of the particle on the slope surface and inside the slope (right)

Fig 7 and 8 show the numerical vibration velocity of the node 3085. The node is 31m far away from the start sites of the blasting. The maximum vertical (z direction) and horizontal (x direction) velocities by numerical computation are 4.76 cm/s and 3.39 cm/s, respectively, while the tested values are 2.11 cm/s and 2.07 cm/s.

Based on the vibration velocity by time and distance from the start site of blasting of every measure point, the maximum velocity can be obtained. The attenuated tendency of the vibration velocity by the distance can be analyzed. Figs 9-12 illustrate the comparisons of numerical and tested attenuated tendency. Table 2 shows the data of particle velocity.

Table2. velocity of monitoring nodes

Node	Location	Distance (*m*)	Vertical velocity (*cm/s*)	Horizontal velocity (*cm/s*)
3562	surface	12.2	7.21	7.10
3588	surface	17.5	6.02	5.37
3045	surface	24.4	5.12	3.86
3075	surface	31.1	4.76	3.39
2395	surface	39.1	4.61	3.94
2435	surface	44.8	3.16	1.82
2368	surface	51.9	2.13	1.22
3721	inside	11.5	5.04	5.69
3312	inside	16.0	4.47	5.17
3308	inside	20.0	3.99	4.83
2662	inside	25.5	3.40	4.38
2658	inside	30.0	3.17	4.14
2068	inside	35.0	2.75	3.84
545	inside	41.0	2.27	3.51

Some conclusions from the analysis above are:

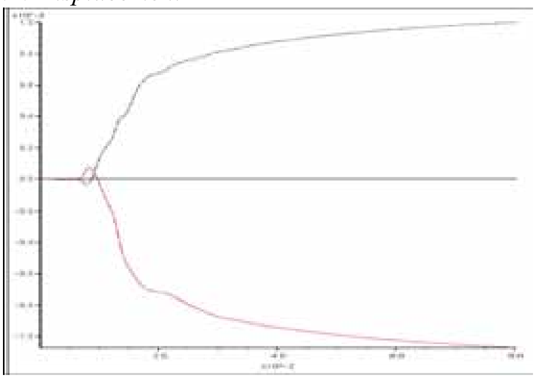
1. The attenuated tendency of the vibration velocity on the slope surface by numerical simulation is consistent with that by field test. Meanwhile, the z-direction velocity on the surface is basically greater than that of the x-direction. The simulated attenuated tendency of peak velocity presents elevation amplification effect. The x-direction vibration peak velocity of node 2395, which is 39.1m far away from

the blasting center and with the height of 30m, does not present attenuated tendency as others do but increase tendency, namely elevation amplification effect. However, the z-direction vibration peak velocity does not present attenuated tendency.

2. The particle vibration velocity by numerical computation is commonly greater than that by field test. This can be explained by not taking rock cranny into consideration in the numerical model. The continuous and uniformity character assumption of the rock medium in the simulation makes the attenuated tendency slow.

3. The particle vibration velocity on the slope surface is generally greater than that inside the slope.

2.4.2. Displacement



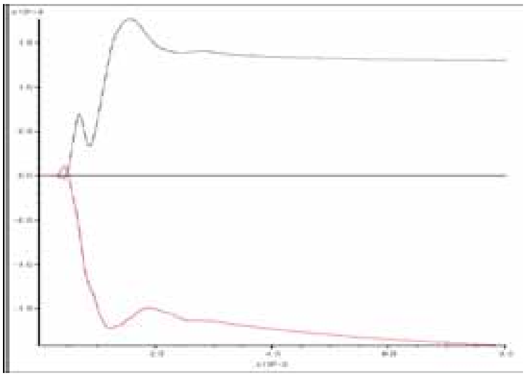


Fig. 13 Displacement time-history curve of node 1945; (left)
Fig. 14 Displacement time-history curve of node 3045 (right)

Table3. Maximum displacement of monitoring nodes

Nodes	location	Distance (*m*)	Horizontal displacement (*mm*)	Vertical displacement (*mm*)
3562	surface	12.2	2.57	1.67
3588	surface	17.5	2.20	1.81
3045	surface	24.4	1.78	1.99
3075	surface	31.1	1.30	2.13
2395	surface	39.1	0.84	2.14
2435	surface	44.8	0.65	1.93
2368	surface	51.9	0.92	1.59
1945	surface	58.1	1.05	1.93
3721	inside	11.5	1.12	0.73
3312	inside	16.0	1.23	0.61
3308	inside	20.0	1.19	0.53
2662	inside	25.5	1.15	0.62
2658	inside	30.0	1.10	0.70
2068	inside	35.0	1.15	0.74

3. Conclusion

Numerical simulation is employed to estimate the dynamic behavior of a high cutting rock slope. The particle vibration velocity and displacement are analyzed and conclusions are drawn as follows:

The particle vibration velocity by numerical computation is basically consistent with that by filed test, but the values obtained by former method are commonly greater than that by later due to the simplification of the explosive. The vibration velocity of the node with the height difference of 30m from the blasting center presents elevation amplification effect. The particle vibration velocity on the slope surface is generally greater than that inside the slope.

The maximum particle x-direction and z-direction displacement are relatively tiny values, 2.57mm and 2.14mm respectively, which means the slope is in the stable state. Meanwhile, the variation of maximum displacement has no rule to comply with. The node displacement on the surface is basically greater than that inside the slope.

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